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Combating Performance Degradation in Highly Mobile Networks Using Rate Control

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COMBATING PERFORMANCE DEGRADATION IN HIGHLY MOBILE NETWORKS USING RATE CONTROL*

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Abstract

We examine a simple technique for combating performance degradation by adjusting the rate of the received signal. Using adaptive demodulation, the receiver can respond to deteriorating conditions trading BER for rate and vice-versa, without involving the transmitter. This way the receiver has more control on the tolerated distortion. The implementation of this technique does not require modifications of the hardware of neither the transmitter nor the receiver, and its application can be very practical. The performance degradation which occurs by receiving a degraded version reliably versus receiving a non-degraded version unreliably, depends on the service and can be very subjective, making this technique very attractive for voice and video communication. This technique, independently or jointly with slow power control, can be a useful tool in network control and resource allocation.

1 Introduction

Military wireless communication systems are designed to operate in a hostile environment with minimum power requirements. The link between any pair of transceivers is corrupted by multipath fluctuations and shadow fading. The system should also be immune to interference from other friendly and jamming signals.

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The common characteristic of most of the techniques developed for combating these impairements at the network level (e.g. fast iterative power control) is that they depend on full knowledge of the gain in all propagation paths, both intended base-mobile paths and interference paths. However, these quantities are very difficult to measure in highly mobile and distributed wireless networks with a very large number of nodes, and even if that was possible, the communication of this control information between nodes increases the traffic and reduces the throughput of the system . Furthermore, changes in the power of one link affect all the other links of the network.

In this work, we investigate alternative practical methods for maintaining reliable communication between the nodes of the system (mobile and stationary). We focus on the use of variable-rate demodulation, where the symbol rate and constellation size are adjusted to maintain an acceptable Bit Error Rate (BER) or Mean Squared Error (MSE) – depending on the type of the traffic – on poor quality connections. This procedure is transparent to the transmitter. Applying this technique, the receiver is able of trading symbol rate for performance, and vice versa, and, thus, of having better control on the tolerated distortion.

Unlike adjusting the transmit power, adjusting the rate of a link is transparent to the physical layer of the coexisting links. However, rate changes cause fluctuations to the traffic load and delay characteristics of the network. Therefore, the use of the aforementioned rate control technique has to be combined with appropriate network control algorithms.

This paper is organized as follows. In the first part,

we present a simple rate control technique of responding to deteriorating conditions by reducing the rate of the received signal. The changes required to the hardware of the receiver are minimal, and easily implemented. The advantages of this method are examined for the cases of two modulation schemes likely to be used in future wireless systems. In the second part of we discuss the aspects of a network control algorithm which takes advantage of the aforementioned method. Extensions with the use of slow power control and adaptive antenna arrays are considered.

2 Passive Rate Control via Adaptive Demodulation

Continuous maintenance of feedback channel between the transmitter and the receiver in highly distributed and mobile wireless networks is occasionally impossible. Moreover, for types of services like broadcasting, multicasting, etc., the traffic load generated by the feedback channel is prohibitive. In these cases, power control is infeasible and all nodes should transmit at the same power level [1]. The lack of the feedback channel also precludes the control of the rate of the transmitted signal by selecting the optimal modulation scheme, based on the existing quality of the link [2].

Passive rate control via adaptive demodulation is a simple technique that the receiver can apply in order to combat the performance degradation caused by fading and interference. As it will become obvious in the following analysis it provides considerable improvement requiring only minor changes to the structure of the receiver.

In the first case, a 8-PSK constellation (3 bits per symbol) is originally used for transmission (Figure 1). The probability of symbol error for this scheme is given by [3]

$$P_8 = 2\, Q\!\left(\sqrt{2\gamma_s}\,\sin\frac{\pi}{8}\right) \tag{1}$$

where γ_s is the SNR per symbol.

When the SNR at the location of the receiver drops below a predetermined threshold (its value will be service–dependent) , the receiver has the option of reducing the rate of the received signal from 3 to 2 bits per symbol. This can be done by adding the outputs of the matched filters that correspond to symbols with the same first two bits (e.g. 000 and 001 are combined to the supersymbol 00) as it is shown in Figure 2. The resulting supersymbols (shown with "x" in Figure 1) form a QPSK constellation.

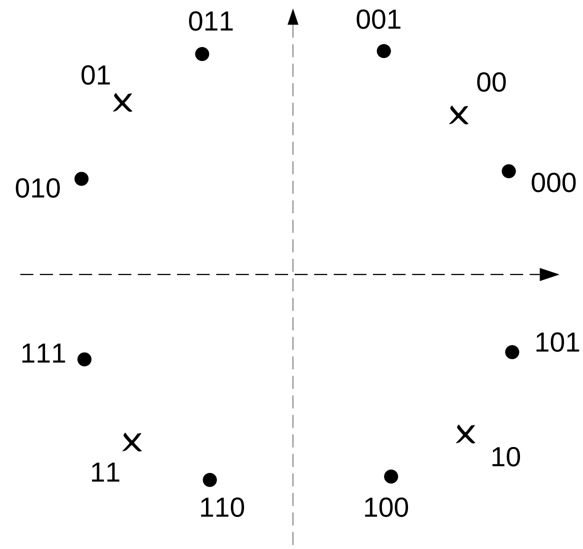

Figure 1: Adaptive demodulation for QPSK. The receiver can decode 2 or 1 bits per symbol.

The probability of symbol error of the QPSK scheme is [3]

$$P_4 = 2\, Q\!\left(\sqrt{\gamma_s'}\right)\left[1 - \frac{1}{2}\, Q\!\left(\sqrt{\gamma_s'}\right)\right] \tag{2}$$

where γ_s' is the SNR per symbol of the modified scheme. It can be shown that γ_s' is approximately equal to the SNR per symbol of the original scheme. We are currently working on the complete analysis, which will be available in a future publication.

The probability of symbol error of the original and modified schemes are plotted in Figure 3 for different values of the SNR per bit. We can see that for a 33% decrease in the rate, the modified scheme provides a 3-4dB advantage over the original scheme. The process can be reversed when the SNR increases, so that the full rate signal is received.

Equivalently, for the uniformly spaced 16-QAM scheme (4 bits per symbol) shown in Figure 4. The probability of symbol error is given by [3]

$$P_{16} = 3\, Q\!\left(\sqrt{\frac{1}{5}\gamma_s}\right)\left[1 - \frac{3}{4}\, Q\!\left(\sqrt{\frac{1}{5}\gamma_s}\right)\right] \tag{3}$$

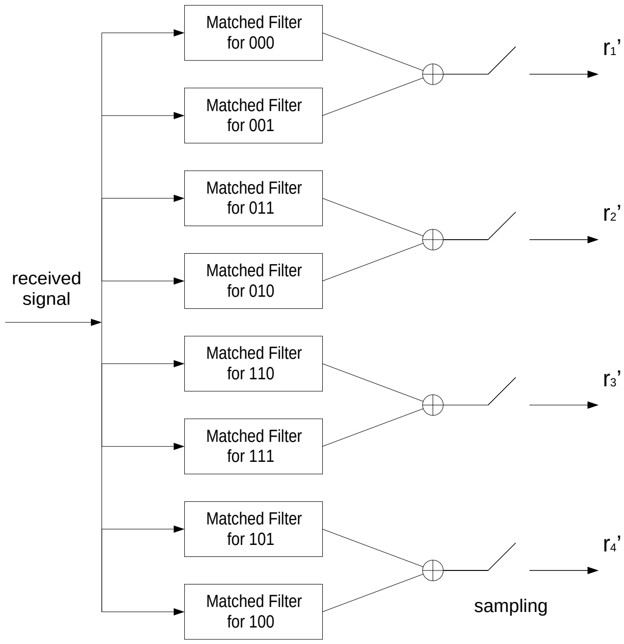

Figure 2: Modified optimum receiver for passive rate control. The received signal is projected to the sum of the adjacent signals.

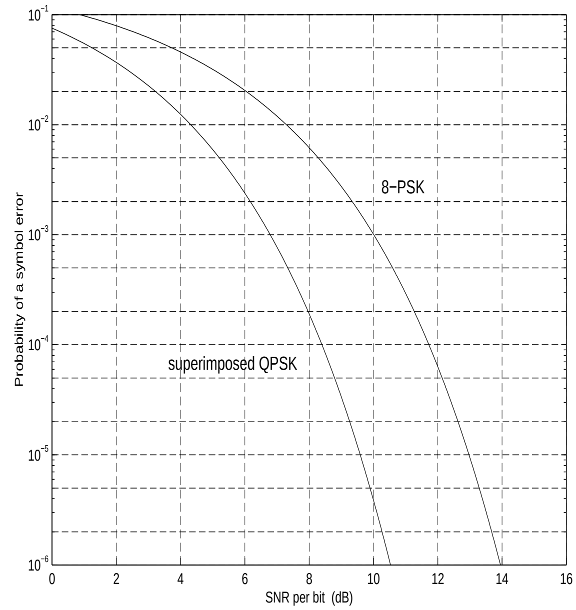

Figure 3: Prob of symbol error for the 8-PSK and the superimposed QPSK schemes.

where γ_s is the SNR per symbol.

When noise and interference exceed tolerance levels, the receiver can decode the first two bits of each symbol with lower probability of error than the entire 4-bit symbol. The resulting supersymbols (shown with "x" in Figure 4) form again a QPSK constellation with probability of symbol error [3]

$$P_4 = 2\, Q\Big(\sqrt{\gamma_s'}\Big)\, \Big[1 - \frac{1}{2}\, Q\Big(\sqrt{\gamma_s'}\Big)\Big] \qquad (4)$$

where γ_s' is the SNR per symbol of the superimposed QPSK scheme, and similarly to the previous example is approximately equal to the SNR per symbol of the original scheme.

In Figure 5, the probability of symbol error of the 16–QAM and modified QPSK schemes are plotted for different values of their equivalent SNR per bit. Here, for a 50% rate decrease, we achieve a 4-5 dB gain in SNR.

Comparing the results of the two examples we see that the larger the rate decrease, the higher the gain we can achieve, which was expected. It is also obvious that the achievable rates depend on the type and size of the constellation. Further improvement in the probability of error can be achieved by using higher-order non-uniformly spaced constellations [4, 5].

Adaptive demodulation can be used with very favorable results when the transmitted bit-stream is hierarchically encoded, i.e. a part of each transmitted symbol carries more important information than the rest of the symbol. For example, the lower frequencies of the voice or image are encoded separately from the higher. In this case, the supersymbols convey the "most important" bits of the transmitted symbols. Therefore, the information lost by reducing the rate of the signal is less than the rate decrease. This loss depends on the service, is subjective and very difficult to quantify.

3 Network Control using Rate and Slow Power Control

We proceed in discussing the aspects of using rate control, by itself or in conjunction with *slow* power control, for network control, i.e. base-station assignment and channel allocation. Slow power control has the advantage that instead of compensating for instantaneous power fluctuations, as the fast power

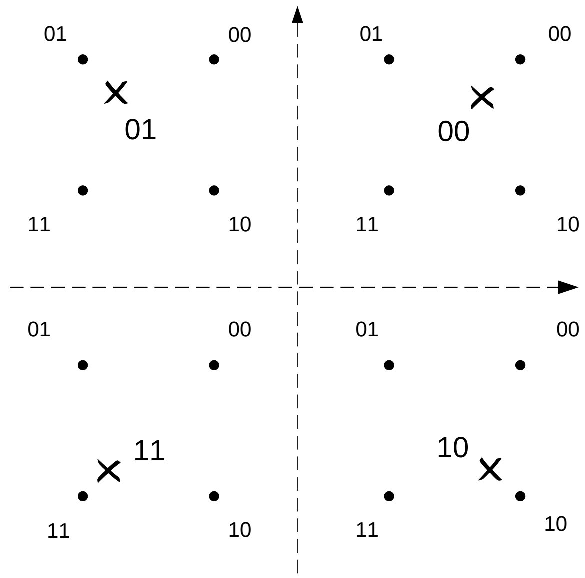

Figure 4: Adaptive demodulation for 16-QAM. The receiver can decode 4, or 2 bits per symbol.

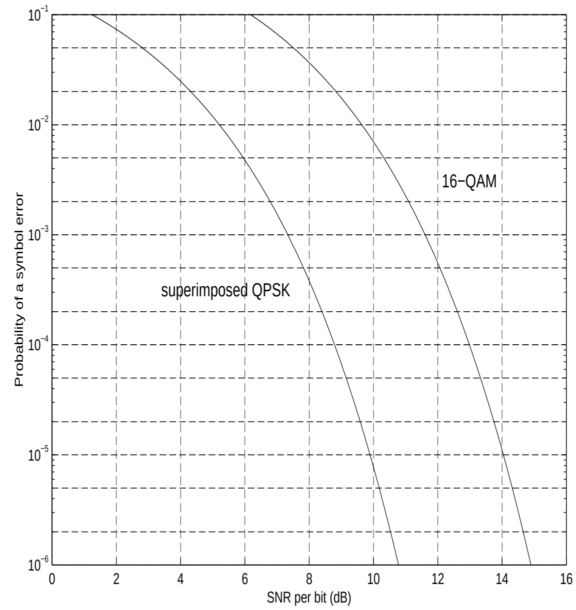

Figure 5: Prob of symbol error for the 16-QAM and the superimposed QPSK schemes.

control algorithms do, attempts to keep constant the *average* of the received power, reducing significantly the complexity and power consumption of the hardware. The combination of rate and power control will provide new degrees of freedom in the efficient allocation of the resources of the network.

Information theoretic results [1, 6] have shown that by combining rate and slow power control considerable improvement in the throughput can be achieved for single-cell multiuser systems. However, the practical implementation of this scheme entails difficulties that are not considered in theoretical studies. Extension of these studies to account for adjacent cell interference is needed in order to obtain results applicable to practical systems.

As an additional extension, we propose the combination of the joint rate and power control scheme with the use of intelligent adaptive signal processing at the antennae of the nodes. Our analysis shows that employment of adaptive antenna arrays results in higher SINR with less power consumption, higher achievable rates, and significant increase in the multiple access capability of the network [7].

4 Conclusions

In this paper we examined adaptive demodulation, a simple technique for combating performance degradation by adjusting the rate of the received signal. Adaptive demodulation is invisible to the transmitter and does not require a permanent feedback channel. It provides the receiver with the ability of responding to deteriorating conditions trading BER for rate and vice-versa, without involving the transmitter. This way the receiver has more control on the tolerated distortion. Only minor modifications to the hardware of the receiver are needed for the implementation of this technique, and its application can be very practical. We illustrated the advantages of adaptive demodulation by applying it to two commonly used modulation schemes. The performance gain was shown to be significant. This technique, independently or jointly with slow power control, can be a useful tool in network control and resource allocation, increasing the agility of the network in adapting to the changing conditions of the communication environment.

Disclaimer

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